CHAPTER 9

SNOW AND ICE CONTROL

9-1. Trafficked area requirements

The requirements of trafficked areas will vary with the type and amount of traffic. The following paragraphs highlight the requirements of several types of traffic application areas.

a. Roads. Wheeled vehicles are impeded by snow and ice on roads, depths approaching 25 percent of the wheel diameter can immobilize a vehicle. Gasoline consumption is increased slightly when tires pass over rutted compacted snow surfaces, by 10 percent when driving through 1 inch of new snow, and by 15 percent through 2 inches of new snow. The coefficient of friction of tires on ice is less than 0.1 near the melting point, and on compacted snow increases to around 0.25, compared to dry pavement values of 0.8 to 1.0 on PCC or AC. In addition to roads, snow can obstruct parking lots, storage areas, railroads, and sidewalks. Therefore, in the interest of safety, mobility and reduction in the costs of operation, snow should be cleared from pavements and ice should be treated or removed. The degree to which these services should be performed will depend on maintenance standards established at the particular location.

b. Runways and heliports. The presence of shallow snow on a runway in itself does not pose a serious hazard to takeoff and landing operations of aircraft. Compacted snow runways have been constructed and used in Alaska, Greenland, and the Antarctic and are adequate for light and heavy aircraft. Hazards arise from three sources.

(1) A completely ice-covered runway which will greatly decrease traction and breaking capability.

(2) The occurrence of patches of snow or ice on a runway which may give rise to differential braking.

(3) The presence of slush which can build up on the underside of an aircraft during the take-off roll which can impair aerodynamic efficiency and increase the take-off weight above the acceptable maximum. Loose dry snow is not a hazard in itself, but fixed wing aircraft, and in particular helicopters, can raise clouds of snow which may seriously impair visibility. For these reasons, it is standard practice to remove all snow from hard-surfaced runways by blading and/or sweeping with a rotary power broom.

c. Encampments. Expedient construction of roads by compaction of snow is practicable in areas where infrequent thaws occur during the winter. Rollers made of corrugated metal pipe and dragged by a tracked vehicle are generally used. This method makes unnecessary the removal of snow, but as more snow accumulates, it must be rolled in place. Ruts, washboard patterns, and drifts are eliminated either by dragging or blading with a bulldozer or grader blade and again rolling. Dry snow churned by wheeled or tracked vehicles becomes sand-like in its consistency and should be bladed off to improve traction.

9-2. Properties of snow and ice

The properties of snow and ice are affected by the conditions under which they were formed. The various conditions include the temperature of the air and the pavement surface, and moisture available in the air.

a. Snow. The thermal and mechanical properties which affect snow removal vary considerably. There are initial differences of snow type controlled by the meteorological conditions prevailing at time of deposition, and further changes result from mechanical and thermal metamorphism subsequent to deposition.

(1) *Density.* Snow density (the mass per unit volume) ranges from less than 6.2 p.c.f. to more than 25 p.c.f. when the snow is dry and undisturbed by traffic. Density is an important index of snow type. Combined with the depth of a snowfall, it is an indicator of the magnitude of a snow removal task. It is measured in the field by weighing a sample of known volume.

(2) *Strength.* Snow strength is dependent on the grain structure and temperature. The grain structure is related to the density of the deposit and the degree of bonding between adjacent grains. It is important to remember that snow strength increases as density increases, age increases, and temperature decreases.

(3) *Energy of disaggregation.* Energy of disaggregation is the work which must be done on a cohesive snow mass in order to pulverize it (by breaking intergranular bonds), and it therefore gives a measure of one energy requirement for a plow. There is a close correlation between rupture strength and energy of disaggregation for dry, bonded snow.

(4) *Water content.* At 32 degrees F liquid water is held in the snow by surface tension. Wet snow tends to adhere to plows and presents rotary plows with different demands than does dry snow. For example, a rotary plow working on light fluffy snow is virtually blowing air; one working on dense dry snow is milling a brittle solid and blowing a mixture of air and ice particles; a plow churning very wet

snow comes close to pumping water. Water content is usually measured by calorimetry in the laboratory. There are no simple and reliable field methods for water content determination currently available. A relative indication is given by making and squeezing snowballs. Cold dry snow will not form snowballs at all while very wet snow from which water can be squeezed will make snowballs. When snow has such a high water content that it takes on fluid properties (e.g. flowing and splashing), it is referred to as slush.

b. Ice. The method with which ice forms will affect its adhesion to the pavement surface and the degree of difficulty involved in its removal.

(1) *Ice formation.* Rain falling on a cold surface and flowing prior to freezing results in a smooth glare, or glaze, ice layer. It appears clear or slightly milky if some air bubbles are frozen in. Glaze ice is tightly bonded to the pavement. If the water droplets striking a cold surface are supercooled, freezing can take place almost instantaneously before any flowing can occur, and the rime ice that results is not tightly bonded to the surface. The large volume of air voids in this type of ice gives it a white appearance. Moisture that condenses on a cold pavement and flows prior to freezing ("black ice") is as well-bonded to the pavement as glaze ice but is generally much thinner. This type of ice forms in some localities particularly in the spring where radiation cooling and calm winds contribute. Ground water or melt water ponded on or flowing over a pavement and subsequently freezing may not be tightly bonded initially if freezing occurs from the atmospheric side. However, if thin sheets of water flow over a cold pavement and freeze from the pavement side, the ice that forms may be glaze ice. Snow which has been compacted by traffic and undergone several freeze-thaw cycles may not have the appearance of ice formed by the mechanisms described above. However, it may be much thicker and uneven and pose more of a hazard to traffic and more of a problem to remove than the other types of ice.

(2) *Factors affecting ice formation.* The air, precipitation, and pavement surface temperature all determine the type of ice that may form. Pavement surface temperature is influenced by solar radiation, the reflectivity of the surface, the specific heat and thermal conductivity of the pavement and subgrade, and the heat content of the underlying soil. Surface temperature can vary considerably along a pavement, and thereby affect the ice formation potential. Subgrade insulation will increase the rate at which a pavement cools because heat flow from the subgrade is interrupted, and therefore, ice may form preferentially early in the winter on insulated pavements in contrast to an uninsulated pave ment. The situation will be reversed in the spring, however, when the pavement will warm more rapidly if insulation reduces the heat loss to the cold soil below. Bridge decks will respond in a similar manner, cooling rapidly in the fall and warming quickly in the spring. Surface temperature fluctuations are more likely to occur during the winter than on other pavements.

9-3. Equipment for snow and ice control

The equipment for snow and ice control can be broken down into either mechanical or chemical treatment processes. The following paragraphs discuss equipment for both types of treatment.

a. Blade plows. Blade plows, also called displacement plows, are mounted on the front of a vehicle and push the snow in a direction at a right angle to the vehicle movement. A one-way blade casts snow in only one direction, generally to the right in those countries with right-hand traffic. A reversible blade (fig 9-1) permits adjustment of the plow for either left or right cast. A V-blade plow casts snow to the right and left simultaneously. Blades are generally mounted on tracks, from V4-ton utility vehicles to 54, 00 pounds GVW units. Graders (motor patrols) are used with either a moldboard alone or with a front-mounted displacement blade. The snow speed of graders reduces their utility in many situations; however, they have been used very effectively for cleanup. Blades can be mounted to the underside of trucks either for applying down pressure for ice removal or for removal of a thin snow cover. Trailing or tailgate blades are used to prevent a cloud of snow from flying in front of the vehicle and obscuring the driver's vision. Side or wing plows are used to extend the plowing width or to cut down high banks or windrows at the side of a road ("high winging").

b. Rotary plows. Rotary plows use one or more rotating elements to break the snow from a continuous cover and to cast it to one side through a directional chute. Single-element rotary plows use one rotary device to break up the snow and to cast it through a chute to one side. Two-element rotary plows (fig 9-2) use separate means of these two functions, either horizontal-axis helical augers or helical open-ribbon cutters for disaggregating the snow and feeding it to a paddle wheel impeller for casting through a chute. Rotary plows can be damaged by ingestion of debris such as rocks, branches, tools, and similar foreign objects; therefore, care must be exercised in preventing such accumulation on pavements routinely cleared of snow.

c. Snow loaders. Rotary plows and front-end loaders are most commonly used to load snow into trucks for hauling to a disposal area, but specialized

Figure 9-1. Reversible blade mounted on a 1/4-ton utility truck.

Figure 9-2. Two-element rotary plow with twin horizontal-axis helical augers.

equipment is also available. The conveyor-type equipment (fig 9-3) gathers the windrowed snow into a collecting box by means of an open helical auger, then rake feeds it to a continuous conveyor belt for lifting into a following tank.

d. Sweepers. Light snowfall, and residue following plowing operations can be removed by power rotary brooms. A high-volume low-pressure airblast at grazing incidence to the pavement assists in cleaning the residue on airfield-type units (fig 9-4).

e. Sidewalk plows. Road equipment is both too large and too heavy for use in clearing sidewalks or other narrow passageways such as are found in warehouse or hanger areas. For this purpose a small tracked vehicle equipped with a rotary plow or a V-blade can be used effectively (fig 9-5).

f. Rollers and drags. These are not true pieces of snow removal equipment, but rather, devices for constructing or maintaining compacted snow roads in areas of prolonged, uninterrupted cold. Rollers, made commonly of corrugated metal pipe, compact the snow, and drags are used to scarify surface irregularities prior to rolling.

g. Solid material applicators. Solid materials are normally applied with tailgate spreaders. The spreader can be either a spinning disk or a roller running the full width of the tailgate. The applicator shall have the means of achieving positive control of the application rate.

h. Liquid material applicators. Liquid materials are normally dispensed by conventional nozzle distributor bars attached to a suitable tank vehicle.

Bituminous distributor trucks are often acceptable for applying the materials. The equipment used shall have a pump and sprayer capable of providing positive control of application.

i. Combination applicators. Vehicles containing both mechanical spreaders and spray equipment to combine solid and liquid materials are used. The liquid material is usually sprayed onto the solid material as the solid material is spread. The pump is driven by the spreader drive shaft providing positive control and proportioning between the liquid and solid materials as applied (fig 9-6).

9-4. Snow control and removal

The expense and time involved in removing snow from a road or runway can be minimized by eliminating obstacles which cause drifting to occur across the pavement. These areas can be kept snowfree or by providing a designed obstacle, properly placed with respect to the area to be protected, which will trap the snow or cause it to accumulate in an acceptable location.

a. Snowdrifting characteristics. Snow particles carried by the wind can come either from new precipitation falling during a storm or from particles which were previously deposited on the surface and later picked up by the wind. Drifting during snowfalls can occur even with very low wind speeds, but appreciably higher speeds are required to pick up snow already deposited and carry it along. If the snow is loose and unbonded, speeds of 7 to 18 miles per hour can lift and transport snow, but if the

Figure 9-3. Belt conveyor unit for truck loading snow.

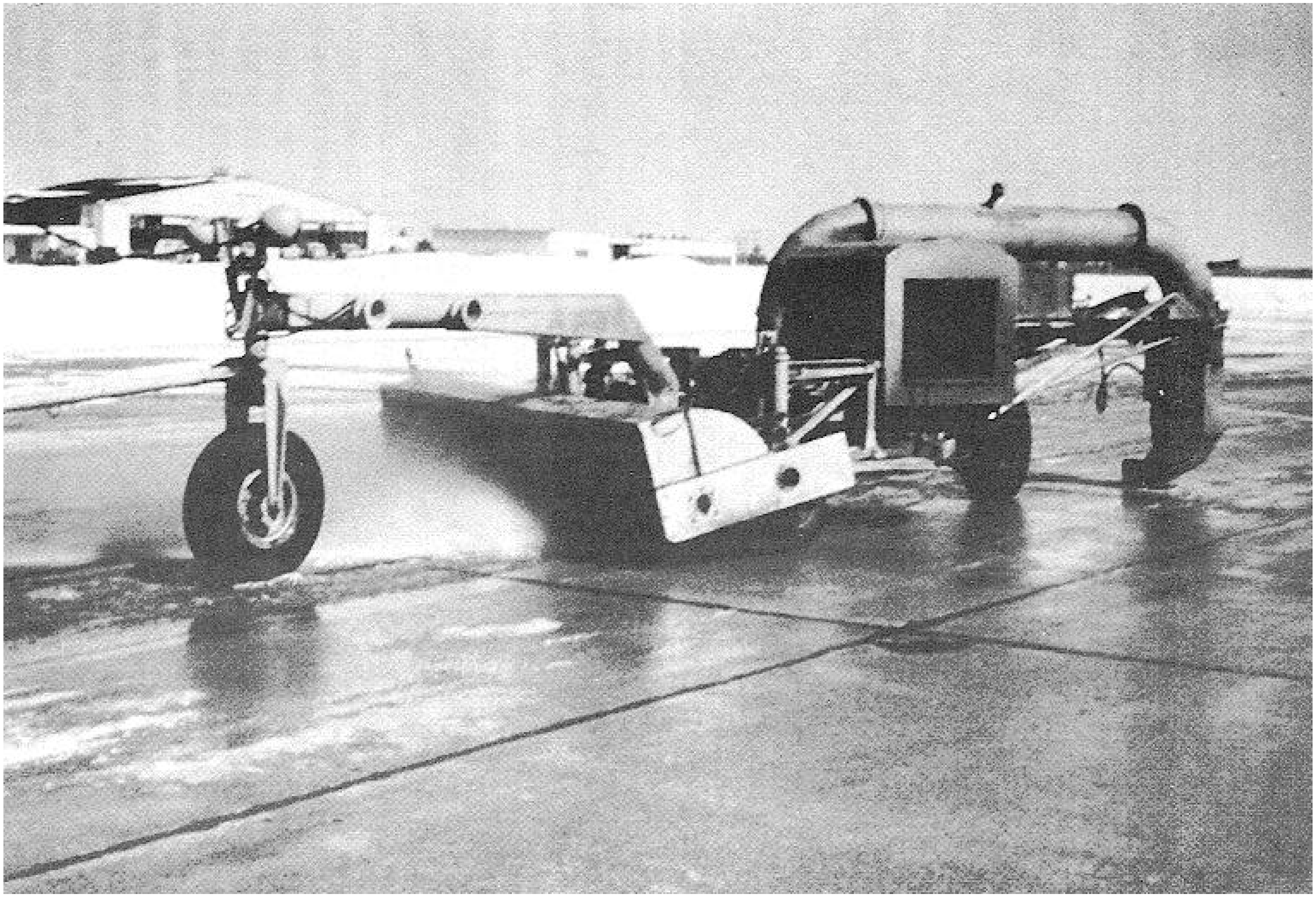

Figure 9-4. Towed power rotary broom with high-volume low-pressure airblast.

Figure 9-5. Small tracked vehicle with V-blade towing a sand spreader

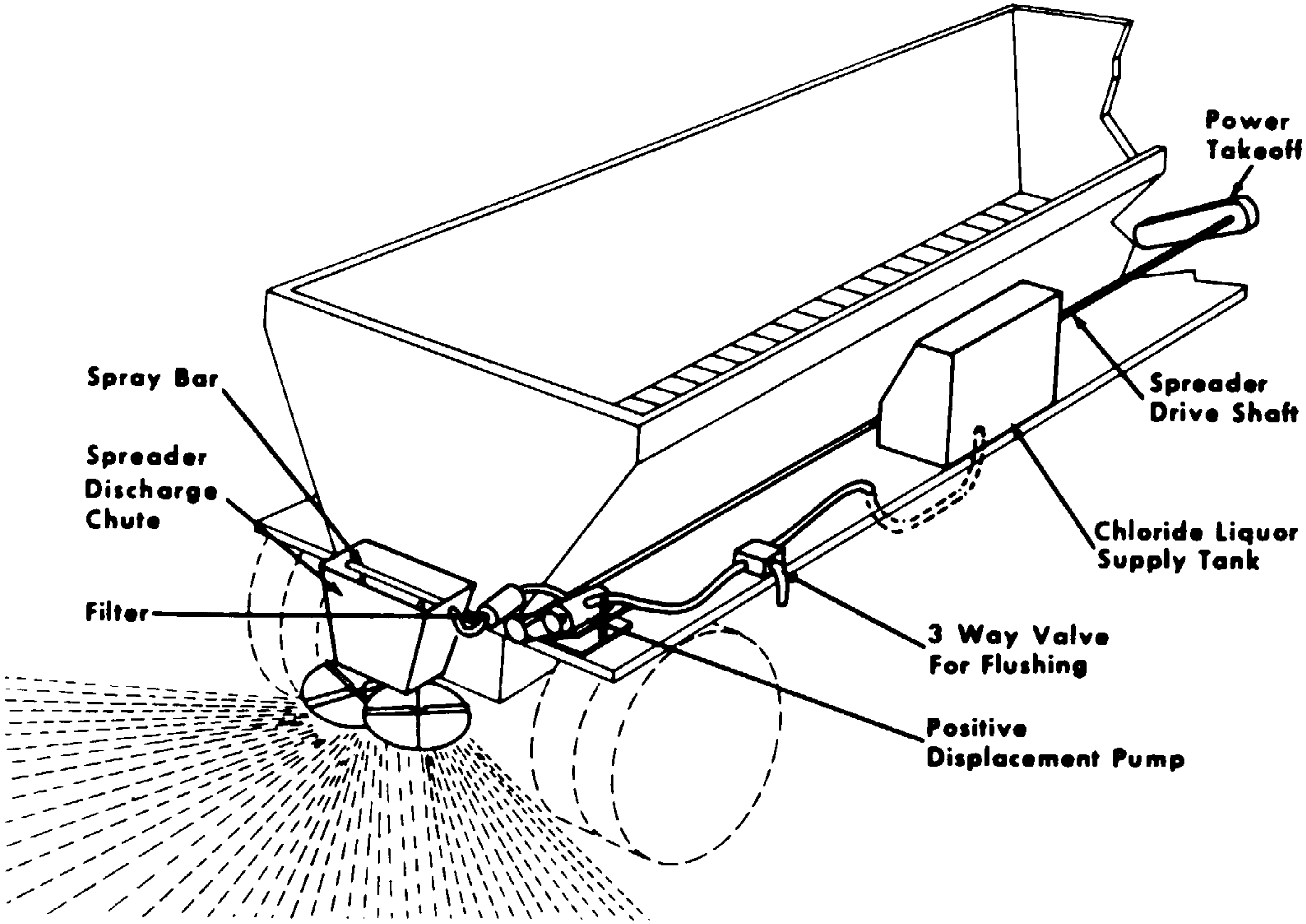

Figure 9-6. Combination applicator

surface is densely packed and firmly bonded by freeze-thawing or age hardening, winds as high as 65 miles per hour may be required for transport.

b. Snow fences. Snow will remain in suspension by turbulent diffusion as long as the wind speed remains above a threshold value. When a change in topography occurs, either a projection above the average surface or a depression below it, eddy currents will develop in which the speed will be reduced below the threshold value and the snow will drop out of the wind stream (fig 9-7). This can occur around buildings or other solid structures as well as on roads built in cuts. Snow fences will store snow for a distance of 10 to 35 times the height of the fence (fig 9-8). Therefore, the fences should generally be placed a minimum of 20 times their height from the area to be protected. A fence will store a limited amount of snow, and when saturated, offers no further protection. For this reason, in regions of frequent drifting snow conditions and few periods of melt, high fences (up to 12 feet) or multiple rows are used or a new fence must be installed on top of the drift that has formed. Typically one tall fence is better than two smaller fences. Fences are most effective when they face broadside into the wind, and arrangements for protecting a road section from winds of different approaches are shown in figure 9-9. Temporary fences will be installed in the fall prior to freezing of the ground and before major snowfalls are expected. In the spring they will be removed, inspected, repaired, or replaced if necessary, and stored in a dry location.

(1) *General.* The common type of snow fence serves as a collector to form a drift upwind of the area to be protected. Studies have shown that a fence of 40 to 50 percent density (i.e., the solid space occupied by the fence material as a fraction of the total frontal area along the fence) and with a gap of 0.1 times the height between the fence bottom and the ground is most advantageous. Within these ranges, the greater the gap, the further the drift is displaced from the fence, but collection efficiency essentially remains constant. The influence of fence density is shown in figure 9-8 where it is evident that the maximum snow volume collected lies between the 42 and 50 percent fence densities. Fence height also influences collected volume (the higher the fence, the greater the volume).

(2) *Artificial fences.* The familiar vertical wood slat fence (fig 9-10) is 4 feet high; the slats are 1V2 by V2 inch with 2 inch openings, thus giving a density of 43 percent. Its bulk and weight of 1.6 pound per running foot have led to the development of alternative materials such as plastic strips attached to posts by stapling or clamping, and plastic woven material (fig 9-11). Other fence designs, some of an expedient type, are shown in figures 9-12 through 9-15. Regardless of the construction material or method, the goal is to reduce the windspeed and allow the snow to drop out of the airstream before it reaches a location requiring protection.

(3) *Plant fences.* Rows of trees and shrubs forming shelterbelts are used as living fences in areas where permanent protection is required and land is available for their growth. An example of a typical shelterbelt is shown in figure 9-16, consisting of a row of low shrubs and two rows of trees. Distance between rows is 10 to 12 feet, spacing of

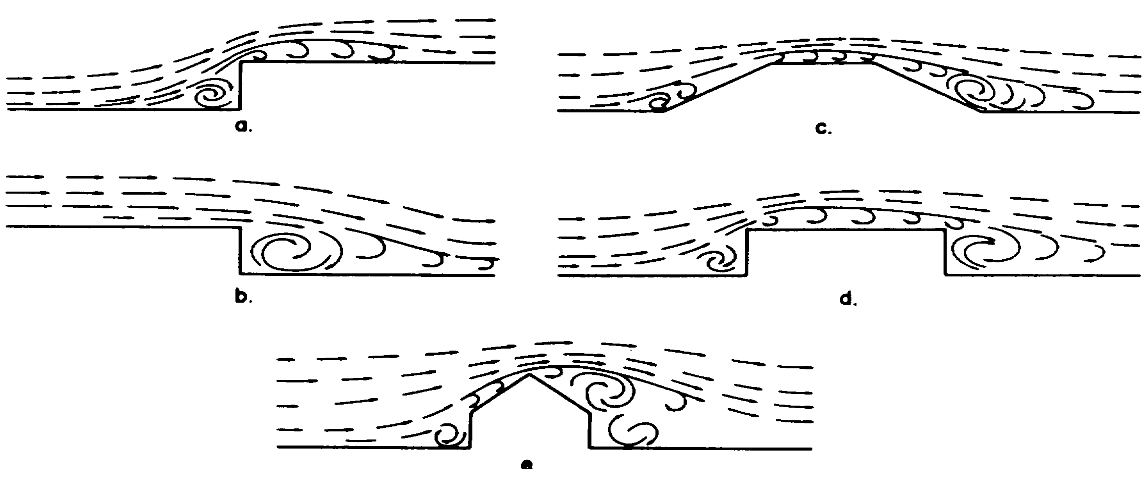

Figure 9-7. Simplified impression of eddies formed by typical obstructions.

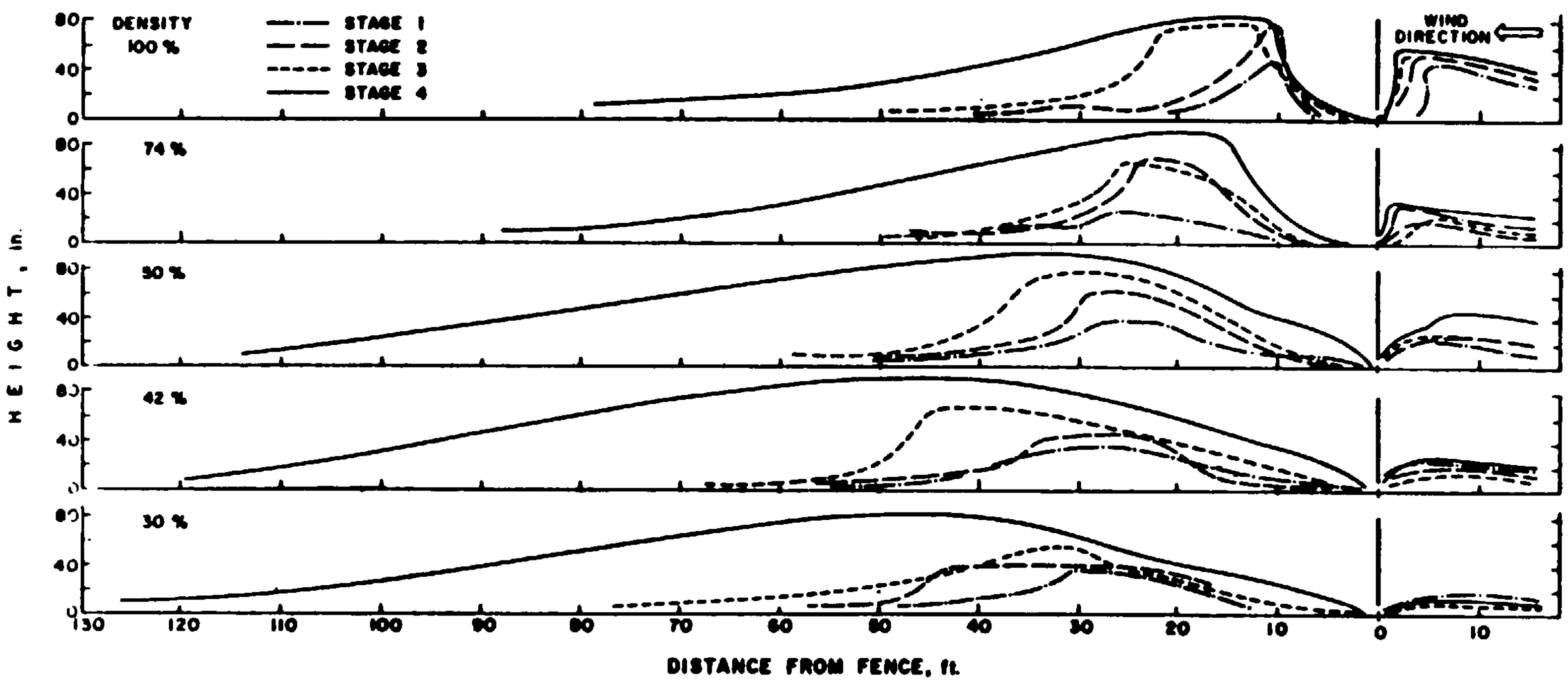

Figure 9-8. Snowdrifts generated by solid snow fences and by vertical slant fences of various densities.

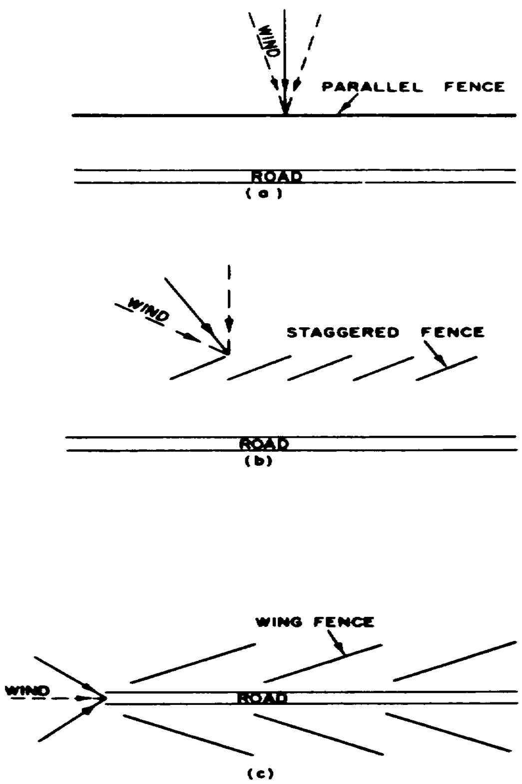

Figure 9-9. Basic arrangements of snow fences for protecting roads or railroads.

the shrubs is 3 feet, and tree spacing in its rows is 6 to 8 feet. A multiple row shelterbelt is much more effective than a single row because of the number of gaps that occur in a single row.

(4) *Snow pile fences*. An expedient protection method utilizes a series of plow cuts in the snow cover to build a windrow of snow to act as a fence. The height and resulting coverage can be extended by repeated plowings.

c. *Road snow removal*. Blade plows are dispatched to plow along routes laid out in a snow removal plan. In making routing assignments, consideration must be given to such factors as grade, width, surface condition of pavement, traffic density, level of maintenance required, occurrence of parked cars, storage space available for the plowed snow on or off the road, shoulder width, and speed limitations when plowing. Also, factors expecting average snow accumulation rate, incidence of wind, and its expected speed and direction must be considered. These factors can be used to determine the frequency of plow passes and the number of pieces of equipment required. On rural-type roads higher truck speeds may be possible, resulting in snow cast well off the road and many miles of coverage. In built-up base areas, parked cars, traffic, curbs, street furniture, and buildings limit both plowing speed and snow storage space, frequently making necessary truck hauling of snow to disposal area.

(1) *Chemical application.* As soon as snow begins falling, equipment should be dispatched over the high priority routes. At temperatures above 20 degrees F and when the weather forecast does not indicate temperatures falling below that level, a light application of salt (sodium chloride) should be made at the rate of 250 pounds per mile (based on a 12-foot wide pavement) to prevent formation of a tight adhesive bond between the snow and the pavement and increase the clearing effectiveness of the plows. Plowing and chemical application can be accomplished simultaneously.

(2) *Coordination*. Plows should not be routed to oppose traffic flow. Echelon plowing is recommended on wide pavements to avoid leaving a windrow on the traveled way between plow passes. However, shoulder clearance can be postponed until the end of a storm, but it is essential that sufficient storage be provided for the next storm by winging back the windrows alongside the road. On divided highways the plow team can cast snow into the median if there is sufficient storage space as well as to the right shoulder. Intersections require particular attention to reduce the windrows left across the road crossing at a right angle to the truck direction.

d. Airfield snow removal. Snow removal must be given priority over aircraft operations on the runways when snow conditions would jeopardize their serviceability and cause the installation to be closed to flying. To do this, close coordination and cooperation must be maintained between snow control and airfield management. Alternate access to the runway by snow and ice control equipment as well as by aircraft is necessary so that airfields are in operational condition at all times. Successful snow removal will depend largely upon the initiative and common sense of the personnel concerned.

(1) *When to start snow removal operations*. Current requirements prevent waiting for weather to improve before starting snow or ice clearing operations. While a variety of techniques are still required to clear snow of various debts from lower priority airfields and other areas, snow clearing on top priority airfield areas must commence with the

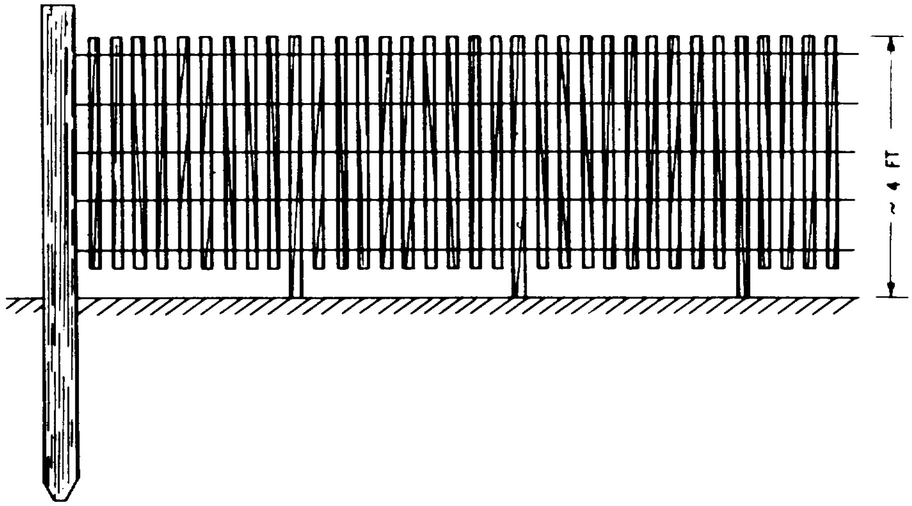

Figure 9-10. Vertical slat fence.

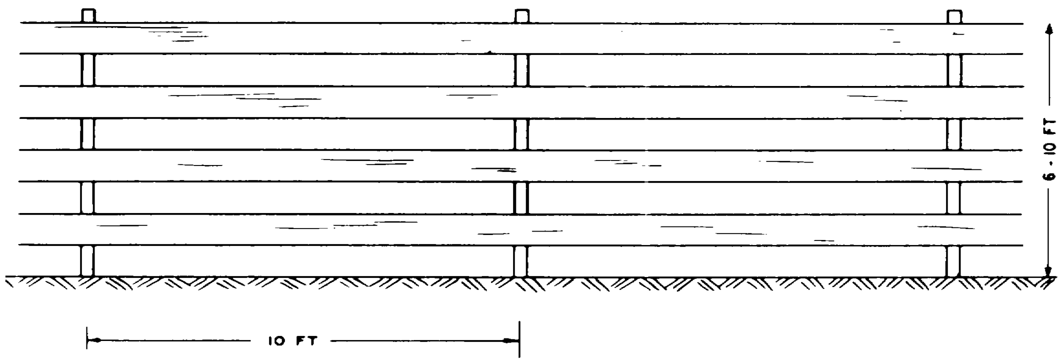

Figure 9-11. Fence made by stapling strips of reinforced paper or plastic strips onto wooden posts.

start of snowfall to provide continuous bare pavement.

(2) Principles of snow removal on airfield areas. The techniques described in this publication are provided only as a guide to be adhered to whenever and wherever possible. However, the following rules are considered vital and must be adhered to:

(a) Start snow removal operations on priority I areas, beginning with the primary instrument runway, immediately when snow begins to accumulate.

(b) During the initial phases, the major effort will be expended on the priority I areas.

(c) The severity of a snowstorm will determine the amount of area to be cleared. The initial plan must provide for clearance of the entire priority I area. Should snowfall increase, prevent clearance of the entire area, reduce operations and concentrate efforts on keeping the center of the primary instrument runway and taxiways open to aircraft movements. If this width will not accommodate operational needs, the operations must be

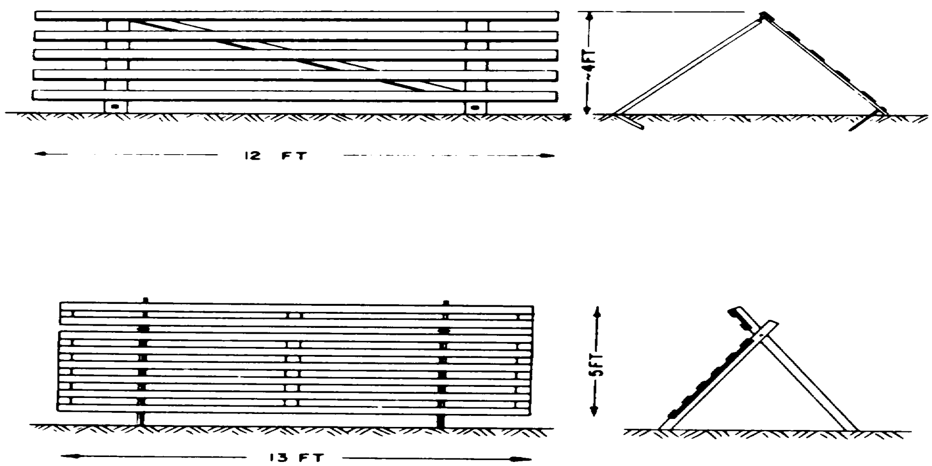

Figure 9-12. Inclined slat fences.

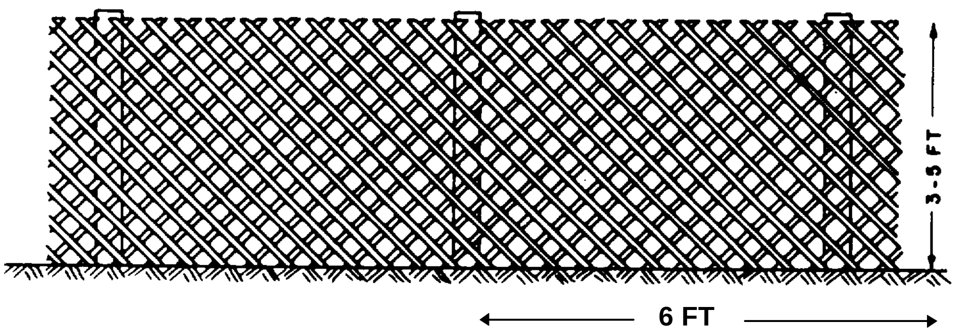

Figure 9-13. Trellis fence.

reduced and efforts concentrated to satisfy requirements.

(3) *Scope of operations*. Airfield snow removal operations will normally include using runway sweepers throughout the duration of the snowfall to maintain the center of the runway in bare pavement condition, regardless of the rate of snowfall. In light-to-moderate snowfall conditions, the scope of the operation should be enlarged to include the entire primary instrument runway, using displacement plows and rotary blowers, as needed, to remove the windrows accumulated by the sweepers. Under heavy snowfall conditions, the scope of the operations may be decreased to concentrate all efforts on keeping the center-line portion open. Wind speed and direction determine the actual clearing pattern to be followed in many instances. It is necessary to maintain a safe distance between vehicles operating within a snow removal pattern so as to avoid accidents resulting from loss of visibility. Equipment movements must be carefully timed and coordinated to ensure an orderly turnaround and a safe reentry at the start of the return trip. Close liaison between the control tower, snow control, and the snow operations supervision must be maintained. The snow control radio net must be monitored at all times in the control tower when equipment is operating on the airfield. Snow removal

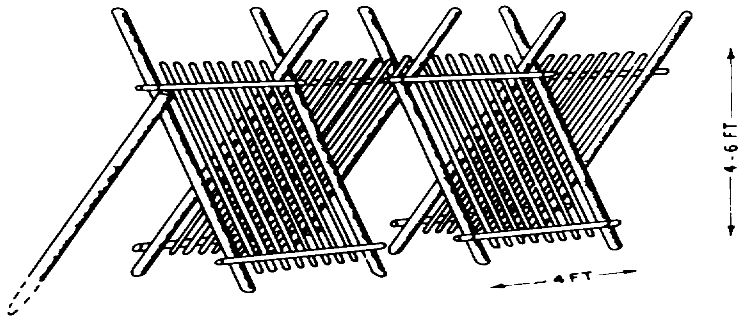

Figure 9-14. Old style russian snow fence.

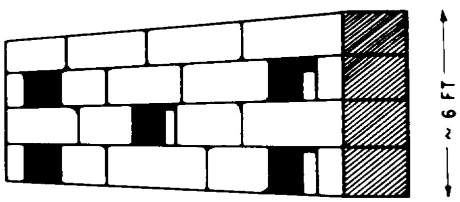

Figure 9-15. Snow block fence.

operations will take priority over other users on a multiple-user net.

(4) *Operations under variable wind conditions*. Still, parallel, nearly parallel, and light wind conditions.

(a) Light snowfall. Under parallel or no wind conditions, snow removal will start at one end of the runway on one side of the center line. When the windrow of snow resulting from the sweeping operations becomes sufficient, a displacement snowplow may be used for disposal. By clearing the center first, the runway is kept in operational readiness and available for aircraft movements.

(b) Heavy snowfall. The procedures and techniques remain basically the same as for a light snowfall, except when the rate of snowfall prevents the available equipment from maintaining full width, bare pavement conditions. One should reduce the scope of operations and concentrate the main effort on the center of the main runway until the snowfall lessens. During a heavy snowfall, the displacement snowplows will make several passes in each direction, accumulating a windrow for the high speed rotary plow to cast over the runway lights.

(5) Cross-wind conditions. High velocity, perpendicular, and strong cross-wind conditions.

(a) Light snowfall. It is permissible to commence snow clearing on the windward side of the runway and move the snow across the runway with the wind, providing time and aircraft operations permit. Once such a clearing pattern is started, it must be completed for the entire width of the runway; otherwise, the runway center line becomes obscured or a windrow is left on the runway. Except in the lightest of snowfall and wind conditions, snow removal during a crosswind will be carried out as described for heavy snowfall.

(b) Heavy snowfall. When a heavy snowfall is accompanied with a strong crosswind, snow removal operations must be concentrated on the runway center-line area. It is recommended that one sweeper in this particular pattern straddle or cover the center line at all times. A high speed displacement plow will be used to remove the windrow formed by the sweepers. Extreme care must be exercised in the end zone of turnaround area when this pattern is in use. The high speed rotary blower, if available, will be used to blow the snow completely off the runway area and over the lights whenever sufficient snow for this operation has been accumulated or windrowed by the high speed displacement plows.

(6) *Clearing runway edge lights*. Lights are an integral part of a runway system and must be maintained in a cleared condition in order to provide runway clearance for aircraft movements. Runway lights may be cleared during snow removal operations by using the air blast from the runway sweepers.

(a) During severe snow conditions, when snow removal operations are concentrated on run-

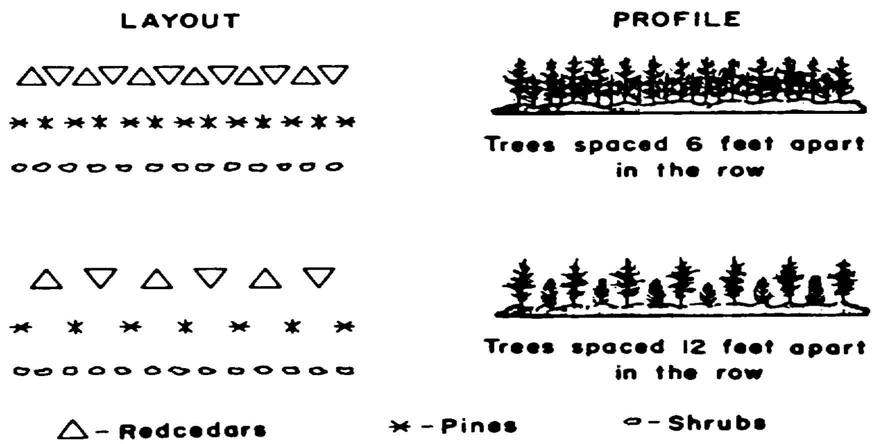

Figure 9-16. Shelterbelt or living snow fence.

way center-line clearing only, one sweeper may be needed to make continual passes to clear the lights. Runway edge lights are generally positioned several inches above the runway surface so that, even under heavy snowfall conditions, it would take considerable time for them to become buried.

(b) During light snowfall operations, a runway sweeper with the airblast chute positioned and adjusted for this purpose will be needed to make the last pass along the rows of runway lights, removing the snow from each light fixture with the air blast.

(c) Under heavy snowfall conditions, it may be necessary to use a displacement plow periodically to clear a path in front of the lights so that the sweeper air blast can be used to clear each one.

(7) *Removing snow and slush from inpavement (semi-flush)* lights. The raise (½2 inch) runway center line, exit taxiway turnoff, and touchdown zone light fixtures will present a problem when packed snow, slush, or ice forms on the pavement. Caution should be used when operating a snowplow over the area. If equipped with a steel blade, it must be adjusted to clear the top of the lights. The sweeper or a blade with rubber cutting edge should be used whenever possible.

(8) *Clearing snow from arresting systems*. Certain small types of snowblowing equipment may be used around barrier installations. Manual labor may be needed to clear snow from the immediate vicinity of the barrier fixtures. This is normally accomplished by barrier maintenance personnel.

(a) Overrun barriers. Overrun arresting barriers are located at the end of the active runway and the beginning of the overrun area. Extreme care must be exercised in clearing snow in the vicinity of this system. Adequate snow removal from the over run area must be accomplished to allow at least 850 feet of runout for this arresting system. It may be necessary to remove the net and cable from the runway during snow removal operation. If this is done, arresting system maintenance personnel must be available for removing and replacing the net and cable at the time of snow removal.

(b) Runway barriers. Barriers located on the runway should be deactivated and the pendant removed before snow removal operations. Snow will be removed to the distance required for effective use of the barrier.

e. Encampment snow removal. Unpaved roads are not plowed to the road surface; therefore, blade plow shoes must be installed and adjusted to keep the blade about an inch above the surface. Plowing speed may be too low to cast the snow well off the road but may tend to leave windrows along the edge. These can cause drifting under blowing snow conditions. Windrows should therefore be eliminated by blading, and a gentle slope (1: 4 is desirable) should be cut along the shoulders. Traction and directional control can be improved on the compacted surface of snow roads by cutting longitudinal grooves with a serrated blade mounted on a grader or under a truck (front-mounting may not achieve sufficient down-pressure to cut grooves). Fresh light snowfall can be rolled to build up the snow base rather than bladed off, and irregularities can be removed with a drag, followed by rolling.

f. Other airfield areas. Snow removal from around the following is done by the facility occupant by hand shoveling, small rotary blowers, and small tractor-mounted plows:

(1) Aircraft hangars and shelters.
(2) Grounding points.

(3) Parked aircraft.

g. Snow disposal. Where there is inadequate storage space for plowed snow, such as in warehouse or other built-up areas, it will be necessary to load and haul snow to a disposal area. Hauling of snow removed from sidewalks near buildings may also be necessary. Either front-end loaders or rotary plows are used for loading. Rotary units are faster and also safer in traffic areas because they eliminate the backing operation required of a front-end loader.

Conveyer units are also used, but they are slower and less maneuverable than rotary plows.

h. Snow control with thermal systems. Applying thermal energy to the pavement by means of embedded heating systems is one of the most effective methods of melting ice and preventing the formation of compacted snow. This is accomplished by installing pipes carrying hot liquid, or cables for electrical resistance heating. However, high cost of capital construction and operation limits application to major problem areas. A heat input of 10 to 20 watts per square foot is required under most conditions to maintain the pavement surface temperature above freezing. High temperatures of the heated elements must be avoided to prevent thermal stress cracking. Application of heat from above the pavement by means of jet engines, weed burners, and pavement planers has been attempted repeatedly with little success. Melting rates are extremely slow, fuel consumption is high, refreezing of poorly drained melt is common, and damage to pavements and joints has been experienced.

9-5. Ice control and removal

Removal of ice from a pavement after it has formed (deicing) requires the expenditure of greater effort and time than does the prevention of ice formation (anti-icing). Two methods of anti-icing are currently utilized: the application of a water-soluble chemical onto the pavement either in liquid or solid form before or during the early stages of an icing occurrence, and the installation of heated sources into pavements to prevent freezing.

a. Chemical deicing. The principal justification for applying deicing chemicals to keep a pavement bare at all times is to prevent the buildup of snowpack. This procedure requires the chemical to be spread on the runway just before or at the start of the freezing condition. This requires accurate information on pavement surface temperature and air temperature along with forecast data. Salt distributed on the pavement during falling snow conditions keeps the snow mealy and prevents the buildup of the compacted snow mass which will adhere tightly to the pavement. In those cases where maintenance crews have not applied sufficient salt in time, a compacted snow mass can build up which may take days to remove by laborious, costly time-consuming, and marginally effective methods. Anti-icing chemicals are most effective at near freezing temperatures. Their effectiveness depends upon the proportion of chemical to water in solution. It is necessary to monitor carefully the surface after the chemical treatment. At the first sign of slushing, the treated area should be swept.

The need for additional chemical will seldom be necessary, except in the case of prolonged freezing precipitation or rapidly dropping temperatures. It is imperative that proper anti-icing techniques be understood and adhered to as chemicals are expensive and only effective under certain conditions. Antiicing or the prevention of the forming of relatively thick (V2 inch) ice or compacted snow on a runway is fairly simple as compared with the cost and effort required to remove it once it has formed. For these reasons, anti-icing procedures should always be used on main runways and taxiways and, when needed, on lower priority airfield areas. In the event that freezing rain turns to snow, the treated area must be swept, followed as required by proper snow removal procedures.

(1) *Common deicing chemicals*. Common deicing chemicals can be divided into three classes: . The first class is solid chemicals and include sodium chloride, NaC1; calcium chloride, CaC12; and urea, CO(NH2)2. The second class is aqueous solutions of crystalline chemicals which include all the solid chemicals dissolved in water. The last class is liquid chemicals, which include ethylene glycol, propylene glycol, and alcohol (ethyl, methyl, propyl, isopropyl).

(2) *Stockpiling of chemicals*. Since deicing chemicals are readily soluble in water, it is clearly desirable to prevent their exposure to water before spreading. Though a crust will form on the surface of sodium chloride and calcium chloride stockpiles, some leaching will take place subsequently during rainfall or when accumulated snow melts. For the most positive protection, chemicals should be stored inside a covered, leakproof shelter. When not stored within a building, the chemicals should be placed on a paved surface and covered with a tarpaulin. Since it is difficult to prevent all leaks by this method, and impossible to keep out all sources of water if loading operations take place during storms, the impervious pad should be pitched to or surrounded by drainage channels which can carry the dissolved salt to a collection basin or a diversion channel. Straight salt should be covered at all times during the winter, but low precipitation and low temperatures during the winter usually make it unnecessary to cover treated sand piles except in special problem areas. When rain does fall on an uncovered

salt pile, it can generate about 625 gallons of brine per inch of rainfall per 1,000 square feet of stockpile. The brine flowing from the base is nearly a saturated solution. On large stockpiles the loss per year can reach about one-eighth of the initial weight of the pile for each inch of rainfall. Salt kept inside buildings is easier to work with than salt stored under plastic covers. It is particularly difficult to cover, uncover, and prevent damage to the plastic cover on stockpiles over 75 tons. Treated sand should be mixed as late as possible to avoid late fall rains which will leach out the salt and upset chemical distribution within the pile. Sand/chemical ratio should be minimized in treated sand piles. The recommended mixture is 80 to 100 pounds of sodium chloride per cubic yard of sand. This amount will freeze-proof the stockpile and should be done early enough in the season to allow the salt to dissolve in the sand. Pile shape should approach a windrow with conical ends for best results. Those measures which can be taken with present facilities should be identified to minimize the effects of stockpile runoff such as diluting salt brine runoff, controlling direction of runoff flow, settling out sand carried in suspension which can smother vegetation, and removing dead vegetation.

b. Ice control with thermal systems. The use of thermal or heat sources to prevent formation of ice can be very effective but in most instances unaffordable as discussed earlier.

c. Chemical removal techniques. Chemicals may be applied to pavements for ice removal. The common chemicals used, sodium chloride (salt) and calcium chloride are extremely corrosive to unprotected metals and must not be used where aircraft will be exposed to the chemical. Noncorrosive chemicals for use on airfield pavement include urea, ethylene, or propylene glycol (or aircraft deicing fluids which are principally glycols), and alcohols. These chemicals are all very expensive, and primary reliance on ice control and removal should be placed on prevention of ice formation. The optimum application rate is based on the level of service required, weather conditions and their change with time, the state and characteristics of the chemicals used, the time of application, the traffic density at time of chemical application, and subsequently, the topography and type of road surface. Determination of the proper application rate is a matter of judgment and a guess about what the weather conditions will be following the application. If a treatment is made based upon the expectation that a storm will continue for several hours, and it does not, the amount applied will have been excessive. It is best to apply a minimum treatment, then apply a second treatment if observation indicates the necessity. Quantities recommended for various weather, snow, and road conditions are given in table 9-1.

(1) *Addition of liquid chemical*. Liquid calcium chloride can provide the needed moisture for initiating the melting action of sodium chloride (rock salt). Field tests have produced the following results: quicker snow melting since the 30 to 45 minute time usually required for brine to form is nearly eliminated, less salt waste as wetted salt does not bounce on ice or snow but adheres and begins to bore through the frozen layer immediately, greater latitude in use of rock salt melting has been experienced with prewetted salt at temperatures as low as 3 degrees F (normal salting is terminated when temperatures drop below 20 degrees F), eventual reduction in amount of salt applied due to the quicker, more effective use of the material, and greater periods of bare pavement surfaces during winter snow and ice storms.

(2) *Road application*. Concentrated spreading of salt, either in a narrow band on two-lane roads or in a 4-foot wide band spread near the centerline crown or on the high side of superelevations, is the most efficient use of chemicals. Here, the purpose is to obtain a concentrated brine in contact with the pavement which will flow under the snow or ice to break the bond and enable traffic and plowing to remove the accumulation. Early exposure to the sun of a portion of the road surface which may be achieved by concentrated spreading will also increase the melting rate by absorption of heat energy. However, unpaved road surfaces will not absorb much solar radiation and therefore melting will be slower. The common gradation of salt requires 8 gallons of liquid per ton of salt to wet the surface of each particle based on an average application rate of 300 pounds per mile distributed at 20 miles per hour. The liquid used is a 32 percent solution of calcium chloride (3.75 pounds of 94 to 97 percent $CaCL_2$ per gallon of solution) which has a eutectic temperature of about -17 degrees F.

(3) *Airfield application*. Neither sodium nor calcium chlorides are permitted to be used on airfields because of their corrosion of aircraft metals. Several approved ice control chemicals may be used under different weather conditions to prevent or eliminate ice from airfield pavements.

(a) Urea. Shotted or prilled urea can provide effective ice control if the temperature is not too low. Of the available chemicals, Urea (Aero)* is the suggested chemical for airport use when the pavement

*Urea (Aero) prills are urea especially formulated for use on airfield pavements and will have a greater concentration of soluble urea than the prilled urea used for agriculture fertilizer, but both are acceptable for use on airfield pavements for ice control.

Table 9-1. Chemical application rates for roads.

Temperature Range	Precipitation Type	Treatment	Rate (lb/mile for Two-Lane Road)	Remarks
Near freeze-ing (30 to 35° F)	Freezing rain	NaC1	200	
	Wet snow	NaC1	500	
20 to 30° F Freezing rain	NaC1	200-400		
	Snow	NaC1	300-500	
	Freezing rain	5:1 NaCi-CaC12	200-300	
	Snow	5:1 NaCl-CaC12	250-400	
Below 20° F Snow	None if pavement and snow are dry			
		3:1 NaCI-CaC12 for removal of compacted snow or	500-600	For heavily traveled roads
		Abrasive for raction improvement	1,200-1,500	For low traffic density roads, or at critical points (e.g., hills, intersections)

Notes: NaCi-CaC12 mix ratios are based on volume measure; CaC1 is 77 to 80% flake (type 1).
When temperature at time of application is falling, use next lower temperature treatment.

surface temperature is above 15 degrees F; urea should never be used below that temperature. The spreading device should be a suitable self-contained granular material-spreading unit having a positive feed mechanism, a spread control device, a 5 to 7 cubic yards capacity, and be suitable for mounting on a snowplow truck. The rate of application suggested for Urea (Aero) prills ranges from 0.32 to 2.17 pounds per square yard, contingent upon the surface temperature and the thickness of the ice (see table 9-2). It is suggested that a test area be used to determine the exact rate of application needed to produce the desired results. Urea is not effective on ice in excess of /4 inch thickness and is most effective on very thin ice. Consequently, ice should be scraped down as thin as possible before resorting to chemicals. Urea for deicing should be applied at the rate of 1 pounds per 100 square feet of pavement surface. As the temperature drops below the mid-twenties, this rate may have to be increased slightly. After urea has been applied, snow removal equipment should remain off the treated area until the chemical has had time to melt or loosen ice. This will vary from about 15 minutes (if the temperature is only several degrees below freezing or the sun is shining) to about 30 minutes under

Table 9-2. Ice-dissolving capacity of urea, pounds per square yard

	Temperature			
Ice Thickness, inch	15° F	20° F	25° F	30° F
1/16	1.09	0.79	0.50	0.16
1/8	2.17	1.59	1.01	0.32
3/16	3.26	2.38	1.51	0.48
1/4	4.35	4.17	2.01	0.64
5/16	5.44	4.96	2.52	0.80
3/8	6.53	5.75	3.02	0.96
7/16	7.62	6.54	3.53	1.12
1/2	8.71	7.33	4.03	1.28

Caution: Whenever urea or other chemicals are used to remove ice, the previous comments on slush and water should be kept in mind. Liquid melt, on top of the ice causes the surface to become very slippery. Aircraft movement surfaces should be reopened to air craft only after a thorough inspection indicates the ice has been completely removed.

more severe conditions. When the ice has melted or has loosened, airblast sweepers should be used to remove slush and water. When the windrow of slush becomes too heavy for the sweepers to handle effectively or has been worked out beyond the limits of the treated area, underbody scraper blades, followed by the sweepers, should be used to scrape off the remaining ice.

(b) Isopropyl alcohol. Grade B isopropyl alcohol is authorized for use as an anti-icing and deicing agent. The proper alcohol mixture is shown in table 9-3. Isopropyl alcohol is effective as an anti-icing

Table 9-3. Freezing point of isopropyl alcohol water mixtures

Percent of Alcohol by Volume	°F
5	29
10	26
15	21
20	17
25	12
30	6
40	- 1
45	- 2
50	- 5
55	- 7
60	-10
65	-12
70	-16
75	-26
80	-43

and deicing agent at temperatures as low as - 12 to - 15 degrees F. It is used undiluted at these temperatures. The isopropyl alcohol mixture should be applied at the rate of 10 gallons per 1,000 square feet or according to the manufacturer's instructions. On layers of ice 1/16 inch or more, application without dilution is advisable. After the ice has been softened or melted by the alcohol, it may be further loosened with the underbody blade and then removed with the airblast sweeper. The sweeper will sweep the liquid and slush off the side and gradually widen the cleared area. A repeat operation may be required in the event of heavy slush. Dilution of the alcohol-water mixture as the melting proceeds may result in a freezable solution.

(c) Ethylene glycol. Ethylene glycol is used as both an anti-icing and deicing agent and normally applied in undiluted form applied at a rate of 4 gallons per 1,000 square feet of surface covered with ¼4-inch ice or according to the manufacturer's instructions.

(4) *Environmental effects of deicing chemicals*. All deicing chemicals are pollutants when present in large concentrations in the environment. Sodium chloride is the largest contributor to pollution because it is used in the greatest quantity. Effects on vegetation are generally confined to within a few feet of the pavement, though splashing and salt spray may affect trees some distance away. Calcium chloride is much less of a pollutant than sodium chloride because of the lesser quantities used and because the calcium ion is less mobile and therefore less assimilated by vegetation. Sodium chloride level must not exceed 250 parts per million in

potable water. The organic deicing chemicals, urea, glycols, and formamide do not seriously affect vegetation. Urea, which is a fertilizer, will stimulate vegetation growth and therefore may increase the need for mowing or vegetation control in affected areas. All the chemicals are toxic to aquatic life at high concentrations: above 10,000 milligrams per liter for urea, above 5,000 milligrams per liter for the glycols, and above 5,000 milligrams per liter for formamide. However, these levels are seldom likely to be reached.

(a) Pavement deterioration from deicing chemicals. PCC pavements may be deteriorated by applying deicing chemicals and subsequent freeze-thaw cycling. The cause is primarily physical in nature, and therefore, the common deicing chemicals (sodium chloride, calcium chloride, urea, ethylene glycol) will also affect the surface to some extent, though calcium chloride will have the least effect because of the low freezing point and therefore the lesser number of freeze-thaw cycles that will normally be encountered. Ammonium salts (ammonium sulfate and ammonium nitrate) react chemically with concrete and cause the serious degradation; they will be avoided. Concrete should contain 5 to 7 percent entrained air for maximum resistance to freeze-thaw. Use of penetrating sealers can reduce the surface degradation, particularly of new concrete.

(b) Pavement sealers. Tests have shown that the most effective sealant is a 1: 1 volume mixture of boiled linseed oil in kerosene. This should be applied in two coats: the first at a rate of 400 square feet per gallon, the second at 600 square feet per gallon. The sealant should not be applied to wet concrete; wet concrete should be allowed to dry for 1 or 2 days at temperatures of 60 to 90 degrees F and relative humidities of 20 to 60 percent before application. The second coat can be applied after the first has dried (several hours at 70 to 80 degrees F); if the concrete was extremely dry, either it will be wetted and allowed to dry for 1 or 2 days or a third linseed oil treatment will be applied. Retreatment will be made annually for the first 3 years of the life of new concrete. After 3 years, little benefit results from sealant applications. Old concrete that has already begun to scale can also be sealed with linseed oil; however, durability is not improved as much as with new concrete. Skid resistance of pavements treated with linseed oil is initially reduced slightly, but to a lesser degree than any other surface treatment that has been investigated. Wet skid resistance values reach the before-treatment values within 24 hours. Bituminious and tar-rubber pavements are not significantly affected by deicing chemicals; only minor degradation of isolated exposed aggregate particles has been observed.

d. Mechanical ice removal methods. Ice is soft and not tightly bonded to pavement near the freezing point, 32 degrees F. As the ice temperature drops, however, both hardness and strength of the adhesive bond increase, and removal difficulty is increased. Front-mounted plow blades are satisfactory for removing ice near the freezing point if the cutting edge is allowed to ride on the pavement. At plowing speeds above about 10 miles per hour, the plow tends to bounce and leave ice on portions of the road; operators should be aware of the characteristics of their equipment in this respect (heavier plows and slower speeds reduce this "proposing" or bouncing). Carbon steel cutting edges run in contact with the pavement wear rapidly; blade changes are frequently necessary during a single shift. Tungsten carbide cutting edges are extremely tough and can last for thousands of miles; however, their brittleness will result in blade chipping when run over pavements with metal projections such as manhole covers or steel rails. Slush and soft ice are removed effectively by rubber blades which squeegee the pavement. Serrated blades which cut grooves in the surface are sometimes used and will facilitate retention of chemicals or abrasives on the traveled way when they might otherwise be blown off. Grooving an ice surface also improves vehicle steering control. Ice is more effectively removed by blades to which a downward force is applied. Though down pressure can be applied by double-acting hydraulic cylinders or separate downloading cylinders on front-mounted plows, underbody blades can apply greater pressure without reducing steering control. Underbody blades must have a trip mechanism to release the blade upon striking an obstacle in order to reduce damage to the blade, truck, pavement insert, and pavement. The moldboard on a grader is similar in function to a truck-mounted underbody blade, even though a grader is sometimes a handicap. Various means have been employed to apply high mechanical loads to the ice surface in an attempt to break it from the pavement. Wobble-wheel rollers, chains, chain flails, and other impact devices have been used, but pavement damage is generally severe, and removal efficacy is marginal, so these methods should be avoided. Abrasives do nothing to prevent the buildup of "pack" but will increase the skid resistance of the surface which can soon be covered by additional snowfall or scattered by traffic action. However, abrasives can be used in such locations as low speed highways and on hills and curves and points of deceleration, that is, locations where fast traffic and aerodynamic forces will not blow the abrasive off the surface promptly. Sand does not remove ice but may insulate it.

In emergency conditions such as the absence of deicing chemicals and the necessary mechanical equipment, icy runway surfaces may be kept in operational condition by using sand. Sand and washed stone used no airfield surfaces should be clean, free running, free from loam or clay with 100 percent passing a No. 4 sieve and not more than 30 percent passing a No. 5 sieve. Dry, clean storage facilities are essential to avoid contamination with road sand which may be treated with calcium or sodium chloride (because of the corrosive effects of chlorides on certain aircraft materials).